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Research paper

Role Minimization as an Optimization Metric in Role Mining Algorithms: a Literature Review

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Abstract

A recent access control model that could accommodate a dynamic structure such as cloud computing can be recognized as role based access control and the role management process of this access control can be identified as role mining. The current trend in role based access control is the role mining problem that can be described as the difficulty to uncover an optimum set of roles from the user-permission assignment. To solve this problem, the researchers have proposed role mining algorithms to produce role set and among the existing algorithms there is an intrinsic topic of the common perception to evaluate the goodness of the generated role set. Eventually, the value of the identified roles could be measured by the preferred metric of optimality namely the number of roles, sizes of user-assignment and permission-assignment and Weighted Structural Complexity. Until now, there is some disagreement on the optimization metric but notably many researchers have agreed on the minimization of the number of roles as a solid metric. This paper discusses an overview of the current state-of-the-art on the recent role mining algorithms that focus on role minimization as an optimization metric to evaluate the goodness of the identified roles.

Keywords: *Access Control; Information Security; Optimization Metric; RBAC; Role Mining*

1. Introduction

A complex organization always needs a method to ensure data authorization and authentication is secured and an access control could offer the solution to this situation. Traditional model for example, Mandatory Access Control (MAC) and Discretionary Access Control (DAC) may not adequate to support a large number of resources and users such as in cloud computing environment [1]. Thus, to accommodate the dynamic and complex structure such as cloud computing, Role Based Access Control (RBAC) is suitable to be implemented.

These studies by [2] and similarly by [3] have revealed that RBAC advantages include the hierarchy element that make the model could be handled efficiently and versatility especially if the organization involve a lot of users. Apart of that, RBAC also can manage the sensitive information from leaking out by implementing least privilege and separation of roles elements. These features enable to make RBAC more powerful, robust and secure model.

Nonetheless, in RBAC, the management of roles can be a big issue and occasionally it is difficult to identify which permissions that related to the user which has been associated with a particular role. Job roles are assigned based on the least privilege but still if some modification has been done to the role, some confusion could be happening especially in deciding which permissions that related to the role [4]. This management process can be identified as role engineering and can be categorized into top-down approach and bottom-up approach. According to [5] the first approach has required the human intervention not only to understand the business practices but also for the process of extracting appropriate roles. In contrast, the aforementioned author has explained that the second method has exploited the current user-permission assignment (UPA) to demarcate roles or this process known as role mining. This process has the advantage of being automated by applying certain algorithms as has been discussed by many authors and has been summarized in publications such as in [6] and [7].

The current trend or one of the main open research in RBAC is the Role Mining Problem (RMP) and 60 publications that relevant to the role development were identified between the year of 2014 and 2016 [8]. According to [7], the difficulty of uncovering an optimum set of roles from the UPA is denoted as RMP and to solve this problem, the researchers have proposed role mining algorithms to produce the intended role set and among the existing algorithms there is an intrinsic topic of the common perception to evaluate the goodness of the generated role set. Eventually, the value of the identified roles could be measured by the preferred metric of optimality or the identicalness between the generated roles with the original UPA.

Among the optimization metrics that could be performed onto the identified roles is reducing either the number of roles (Basic-RMP) [9], sizes of user-assignment (UA) and permission-assignment (PA) [10] and even Weighted Structural Complexity (WSC) [11]. Until now, there is some disagreement on the optimization metric but notably many researchers have agreed on the minimization of the number of roles as a solid metric. Numerous researches have highlighting the minimal of number of roles as the method to evaluate the goodness of the generated roles. This paper offers a survey on the recent role mining algorithms that focus on role minimization as an optimization metric to evaluate the goodness of the identified roles and then we classify those publications according to the proposed solutions for role minimization.

The remainder of the paper is structured as follows. Section 2 presents a background study of this work specifically the classifi-

cation of the solutions that involve in minimization of the number of roles. Section 3 discusses the limitations of existing work and the future works that can lead to further enhancement of this field and lastly Section 4 conclude this.

2. Literature Review

One of the main open research in RBAC is the Role Mining Problem (RMP) and to solve this problem, the researchers have designed and developed role mining algorithms to produce intended role set and the value of the identified roles could be measured by the preferred metric of optimality. Until now, there is some disparity on the optimization metric but many researchers have agreed on the minimization of the number of roles as a solid metric.
Therefore, this paper analyzes a number of role mining algorithms for role minimization to provide the state-of-the-art overview. This section also presents the essential concepts in Role Based Access Control (RBAC) as well as Role Mining Problem (RMP) along with its variant.

2.1. Role Based Access Control (RBAC)

Sandhu et al. [12] was the first researchers that introduced the concept of RBAC model and the relationship between users-roles-permissions and then Coyne [13] has presented the concept of role engineering of being a method to define roles and assigning permissions to the designated roles. The RBAC model comprises of these elements [12][14]:

- U represents user, P is permission and R as role;
- $PA \subseteq P \times R$, a many-to-many mapping of permission to role assignments;
- $UA \subseteq U \times R$, a many-to-many user to role assignment relationships;
- $RH \subseteq R \times R$, the inheritance of roles to roles;
- Perm $(R) = *p \in P \mid (p, R) \in PA+$, the mapping of role R onto a set of permissions.
- User $(R) = *u \in U \mid (u, R) \in UA+$, the mapping of role R onto a set of users.

The primary RBAC references models as have been discussed by [12] and similarly according to [15] have consisted of RBAC0 as the basic model, while RBAC1, RBAC2 and RBAC3 can be considered as the advanced models. RBAC0 contains core elements of RBAC policies. The core of RBAC generally can be listed as the following: (i) Users (U), (ii) Roles (R), (iii) Sessions (S) and (iv) Permissions (P) as well as the relationships between them namely user assignment (UA) and permission assignment (PA). Next Role Hierarchy (RH) concept is proposed in RBAC1. RH can transform the organization's authority and responsibility into roles and RH is also structuring roles into dominant roles or known as senior roles and less Meanwhile the element of constraints is the most important mechanism in RBAC and has been presented in RBAC2. Constraints can be used to enforce restrictions especially on relationship as in abovementioned models, such as UA, PA, Sessions (S) and Role Hierarchy (RH). There are many applicable constraints that existed, but the common one is the Separation of Duties that specified two conflicted roles cannot be allocated to the same person at the same period while cardinality constraints limit the highest users that can be appointed to an exact role. Lastly, RBAC3 combines all elements in RBAC0, RBAC1 and RBAC2. Moreover, constraints can be applied to the role hierarchy (RH) [12] [15].
As stated in the aforementioned section, the role engineering can be apportioned into two categorized so the next section would explain role mining (RM) and role mining problem (RMP).

2.2. Role Mining Problem (RMP)

According to [5], a complete state of RBC in the RBAC system could be formalized as follows: system as the input, $\rho = \langle U, P, U P \rangle$ where U is a set of user, P is a set of permissions, and the output or the generated RBAC should be represented by $\gamma = \langle R,UA,PA,RH \rangle$ where R is a set of roles, $UA \subseteq U \times R$ is the user role assignments relation, $PA \subseteq R \times P$ is the role permission assignments relation, and $RH \subseteq R \times R$ is called a role hierarchy. The definition of role mining according the authors is a process to uncover an optimum role from UPA that denoted as a Boolean matrix. In the matrix, UPA is specified the relationship between the users and permissions; correspondingly, the rows and columns is equivalent to users and permissions, and the entry of the matrix is designated with a 1, a user is appointed to a specific permission; otherwise, it contains a 0. Similarly, the authors [16] have described that the generated RBAC system, UA and PA relationships can be elucidate as Boolean matrices and could be depicted in Table 1 and Table 2 [7].

Table 1: Example of UPA

	p1	p2	p3	p4
u1	1	0	0	1
u2	1	1	0	1
u3	1	0	1	1
u4	1	1	0	0

Table 2: Example of UPA

	p1	p2	p3	p4
r1	1	0	0	1
r2	1	1	0	1
r3	1	0	1	1
	r1	r2	r3	
u1	1	0	0	
u2	1	1	0	
u3	1	0	1	
u4	1	1	0	

The authors in [17] has described RMP as an obstruction to acquire ideal roles from the current existing UPA and eventually lead to the default to get a better RBAC system. Moreover, according to [7], the difficulty of determining an optimum roles from the UPA is denoted as the Role Mining Problem (RMP) and it is usually to optimize with certain conditions such as minimization of one or more metrics.

2.3. Role Minimization

Numerous metrics have been investigated and introduced for optimality during role mining and until now and as highlighted by [17] and similarly agreed by [7], five major metrics or factors that could be applied to assess the optimization of a generated RBAC; |R| implies the number of roles, |UA| denotes the number of user-role assignments, |PA| as the number of role-permission assignments, |DUPA| implies the number of direct user-permission assignments, and |t_reduce(RH)| as the number of edges in the reduced role hierarchy. Moreover, the Weighted Structural Complexity (WSC) measure presented by [17], which sums up the above five factors also could be considered as an optimization metric. However, until now, there is no mutual understanding on which metric is the best for the goodness of a RBAC algorithms but many of the researchers have agreed on the minimum of the number of roles.
The formal formulations of minimization of roles have been discovered and discussed by [18] and has furthered explain by [7] in this manner:

2.3.1. Basic Role Mining Problem (Basic-RMP)

Basic-RMP can be expressed as a difficulty to discover a minimum set of roles from an existing UPA hence the number of generated roles is recognized as the optimization metric. In [18] explained that Basic-RMP as follows:

Definition 2.1: *Assumed that U as a set of users, P as a set of permissions and UPA as a user-permission assignment relation then R as a set of roles, UA as a user-role assignment relation, and PA as a role-permission assignment relation should be discovered and consistent with the UPA while minimizing the* $|R|$.

Definition 2.2: To define Basic-RMP using matrix representation, let $|U| = m$, $|P| = n$, and $|R| = k$. Thus, UA is of size m×k, PA is size of k×n, and UPA is of size m×n so a UPA is provided, uncover R, UA, and PA by minimalizing the number of roles, $|R| = k$, such that

$$||UA \otimes PA - UPA||_1 = 0 \quad (1)$$

where: $||.||_1$ = L1 norm
$\otimes$= Boolean matrix multiplication
The authors also have deliberated the δ-Approximation Role Mining Problem (δ-Approx RMP) as a variation that involved with the Basic RMP.

2.3.2. Δ-Approximation Role Mining Problem

δ-Approximation Role Mining Problem (δ-Approx RMP) could be used to determine the minimal roles and allow some minor imprecision if the decomposition of UPA has not generated the original UPA. The definition is as followed:

Definition 2.3: Given a set of users U, a set of permissions P, a user-permission assignment UPA, and a threshold δ, find a set of roles R, a user-role assignment UA, and a role-permission assignment PA, δ-consistent with UPA and minimizing the number of roles, k, such that

$$||UA \otimes PA - UPA||_1 \leq \delta \quad (2)$$

Numerous researches have highlighting the minimal of number of roles as the method to evaluate the goodness of the generated roles. In [19] the authors have presented three criteria that could be considered as an optimization metric and one of them is the basic role mining and this consistent with the discussion of [20] that also has showed through experiments and discussion that the minimal set of roles as precise set because the set could represent the good descriptive roles from the existing UPA.
Furthermore, the authors have described the algorithms that could extract the minimum number of roles from the RBAC system [21]. The above finding is consistent with the study by [22]. The authors have examined the advantages of having minimum roles in a RBAC system. Firstly, if the number of the roles are small, the noises that have come with them would be minimum and because of that role mining algorithms would enable to exclude the noise efficiently and secondly, if the number of roles are small, they could comprise most of the permissions so the roles could indicate the real system.
In addition, the authors have proposed a user-oriented RMP that could equalize between the need of a RBAC system that user-friendly with a system that functional efficiently and among the mentioned evaluation metrics, the minimization of generated roles has been demonstrated as the most useful one to represent the goodness of the identified roles and also the most studied metric [9]. Additionally, [16] also discovered that the most outstanding metric to optimize a role mining is total of roles that generated and weighted structural complexity and similarly in [23] and [24] has uncovered the number of roles or specifically role minimization as an optimization criteria to discover a good or quality set of roles.

2.4 Classifications of Role Mining Algorithms for Role Minimization

In this section, we would discourse some of the recent role mining algorithms that focus on role minimization as an optimization metric to evaluate the goodness the identified roles from 2015 to 2017 and we classify the recent role mining publications according to the proposed solutions for role minimization. The classification of the solutions or algorithms is adopted from [7] and implemented through a systematic review as in [8].
In general, the role mining algorithms for role minimization can be classified into five main strategies namely Problem Mapping Based Strategies, Matrix Decomposition Based Strategies, Graph Based Strategies, Data Mining and Optimization Based Strategies and Semantic Based Strategies. The method and main advantage of each algorithms are accessible in below section while the Section 3 summarize the probable research based on the disadvantage of each algorithms.

2.4.1. Problem Mapping Based Strategies

Many of the existing algorithms have manipulated the Basic-RMP and mapped them to several other problems. The research study by [9] has identified the need to investigate the RMP from the perspective of a user by introducing the limit of roles that can be owned and the authors have formulated four explicit problems namely the user RMP, the approximate user RMP, the personalized RMP, and the approximate personalized RMP. Based on these problems, they have proposed an algorithm to identify the candidate role generation dynamically. In the meantime, the authors have provided in-depth analysis of two constraints that dual to each other called as Constrained Role Mining Problem and the constraints are a role-usage cardinality constraint that limits the highest number of roles for a user to possess while its double, the permission-distribution cardinality constraint restricts the most number of roles that a permission can own. By introducing the two frameworks, they have utilized the minimum biclique cover (MBC) method to test both frameworks [25].
In [26] has described and formulated the Set Cover Problems that consisted of two role mining problems; Basic-RMP to Set Cover Problem and Edge-RMP as weighted set cover problem and moreover they have designed two greedy algorithms that could overcome those problems. Furthermore, according to [27], RMP could be defined as Cardinality Constrained-Mutually Exclusive Task Minimum User Problem (CMUP) by using hypergraphs. CMUP could be described as the minimum users that could execute a task while satisfying the security constraints. Then they have proposed a greedy solution to solve the aforementioned problem. In a different study, [16] has examined the problem to find least set of roles of a temporal user-permission assignments or can be recognized as Temporal-RBAC (TRBAC) mode and has formulated them as Generalized Temporal Role Mining Problem (GTRMP). They have recommended a greedy algorithm that could be summarized as to obtain candidate roles from a temporal user-permission assignments (TUPA) and then select the least roles to be appointed to the user.

2.4.2. Matrix Decomposition Based Strategies

A lot of the researches are modelling RMP to a Boolean Matrix Decomposition (BMD) problem as role mining also could be defined as Role Mining Boolean matrix decomposition that decomposed into two Boolean matrices. The authors in [22] have explained that the objective of the BMD problem is to discover a Boolean matrix decomposition solution for an input to a Boolean matrix.
In this paper, the authors have specified a framework to model BMD and a number of variants name usage RMP, basic RMP, δ-approximate RMP, and edge RMP by applying integer linear programming (ILP). Additionally, the authors have used propositional logic to introduce the formal model and then has applied the satisfiability modulo theories (SMT) solvers to articulate the model [5].
According to [28], δ-Approx Important Role Mining Problem (δ-IRMP) has been introduced to solve the problem of δ-Approx RMP [18] which has overlooked the importance of permission in

their solution, so the authors presented δ-IRMP that has classified the permissions based on their importance and can be designated into two parts; the first define the permission to be assigned to a few users and second, the users that should be authorized with few permissions.
More recently, the authors [29] have investigated temporal role mining problem (TRMP) as a BMD problem and has studied an operator called Boolean-set multiplication operator that able to multiply a set with a Boolean value. Furthermore, they have defined a solution of a greedy algorithm to the problem that has employed the utilize the notion of many-valued concepts technique. Similarly, the authors [30] have argued that most of the existing solutions or algorithms are developed in the sense of information that complete but in real-life the data is usually incomplete. Hence, the authors have examined the difficulty of role mining process with incomplete knowledge in the activity logs and they have initiated two variants, explicitly minimal noise (MinNoise) RMP and multiple factor optimization (MFO) RMP and they also have adopted existing k-NN method as the data cleansing technique [31].

2.4.3. Graph Based Strategies

Graph-based methods are usually favoured because of the capabilities of easy navigation, view and manipulation of role structure [32]. Therefore, many graph-based solutions have been introduced to solve basic-RMP. The authors have analysed graph theory to model a data-centric quality estimation (DCQE) model and suggested a framework that capable to identify the output based on minimum of role or edge concentration without executing any role mining algorithms [24].

2.4.4. Data mining and Optimization Based Strategies

Data mining and optimization techniques have been used by many researchers as the fundamental method in designing and developing a role mining algorithm. The study by [33] has examined the application of Constraint Satisfaction Problem (CSP) technique to formulate better quality of UPA by eliminating any redundancy in the UPA. The authors in [23] also has provided a naïve approach that known as RMP SoD that intends to discover a number of roles that not only minimize but also could properly impose the required SoD constraints and the solutions could be allocated into SoD-aware and post-processing.
According to the authors, the previous researches have neglected to consider the number of roles as an optimization metric in User Authorization Query (UAQ) problem and the principle of this UAQ is to determine which set of roles to be triggered for a set of permissions that have been requested by the user. Hence, the authors have refined the UAQ problem by segregating it into exact match, safe match and available match and then recommended the employing of static pruning, pre-processing and the depth-first search based algorithm to decrease the executing time [34]. Meanwhile, the authors in [35] [36] have proposed the capability of answer set programming (ASP) to comply with the constraints that can sustain various optimization objectives at the same time and the ASP is known as a method to declarative problem solving. The proposed ASP-based algorithm named constrained role miner (CRM). In addition, the genetic algorithm has been utilized to design and reconfigure a RBAC scheme that could handle variants such as Basic-RMP, Edge, Minimal Noise-RMP and δ-Approx RMP.

2.4.5. Semantic Based Strategies

Semantic based strategies in role mining are very needed because the nature of a RBAC system that always changing therefore there are always exist the opportunity to find a solution that not only could reconfigure RBAC optimally but also without neglecting the meaningful relationship between the roles. Subsequently, [37] have formulated, designed and developed a heuristic algorithm for log-based RBAC reconfiguration approach that could manage minimal roles and perturbation.

3. Future Works

The key objective of this paper is to explore different techniques to resolve the Basic-RMP and its variant; δ-Approx RMP that emphasis on the role minimization as an optimization to evaluate the goodness the identified roles. However, even with various works on the role mining, there are still some improvement could be investigated and extended so in this section, based on the algorithms in Section 2, we identify some of the potential research that can signify the further enrichment of this issue.

3.1. Dynamic Solutions

Many of the existing solutions have concentrated on recommending static solutions for solving RMP for example by assuming that the same constraint is compulsory to everyone but in some of the cases, the need of a dynamic approach is very much needed such as a solution that could personalize constraint because of the constraints are always changing. Moreover, dynamic solutions also must consider the influence of different permissions such as some permissions should be prioritized than other permissions.

3.2. Noise/ Incomplete Information

One of the research area that could be explored is in certain cases, the information that is needed is either incomplete or could contain flaws or noises and to mine roles from such environment, could resulting errors. There is a few researches throughout the years that focusing on noise or incomplete information but this area could be more scrutinized such as by designing and developing a data cleansing approaches that could use more dynamic machine learning algorithms or statistical measures.

3.3. Semantically Meaningful Role Mining

Meaningful information is very important to determine a better output of a set of roles and this issue has obtained a little attention by researchers therefore the need to propose algorithms that could mine meaningful information are desired by working on for example intelligent and adaptive learning algorithms to extract a semantic meaningful role. Moreover, semantically meaningful a set of roles could be produced by hybrid role engineering techniques or frameworks and hybrid role mining could be described as the process of deriving roles from bottom-up and top-down information.

4. Conclusion

In recent years, the development of role mining algorithms has been prospered and the quality of the resulting identified roles can be measured in the term of optimization metrics such as minimizing either the number of roles (Basic-RMP), the Weighted Structural Complexity (WSC) or the sizes of UA and PA. Therefore, the purpose of this paper is to investigate and classify the role mining algorithms that focus on role minimization as an optimization metric to evaluate the goodness of the identified roles and we also categorize some of the gaps for the future direction for researchers.

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